XII. INTERNATIONAL CONFERENCE ON HADRON SPECTROSCOPY

Istituto Nazionale di Fisica Nucleare

HadronPhysics I3 Study of Strongly Interacting Matter

8-13 OCTOBER 2007

Laboratori Nazionali di Frascati (Rome)

Detector Design for ILC

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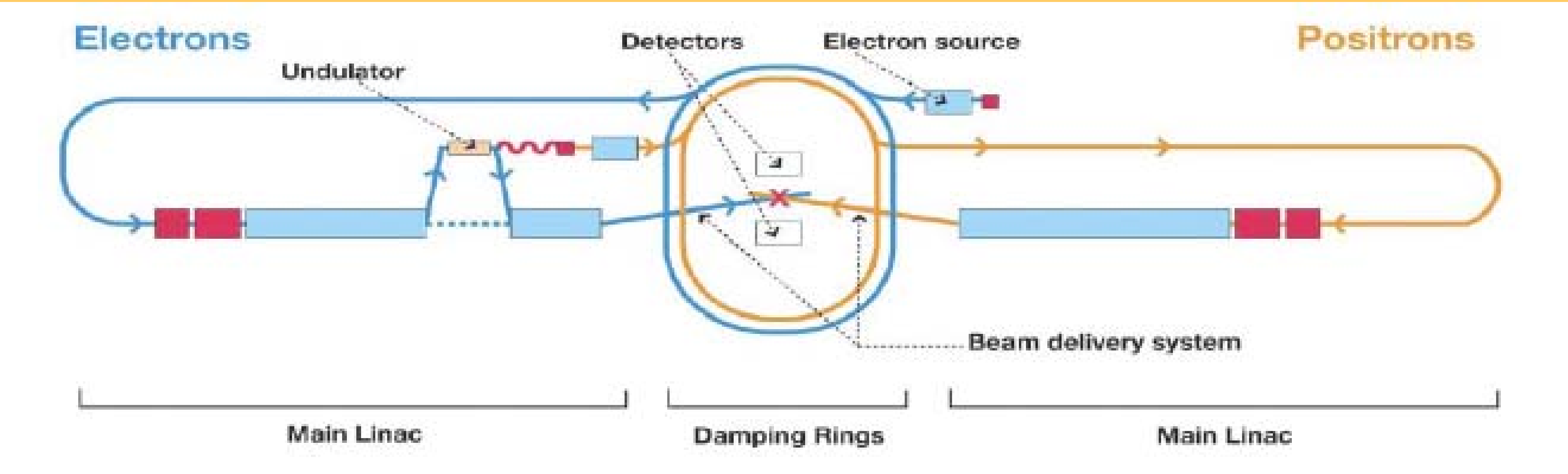
Most information given here is publicly available at:
http://www.linearcollider.org/wiki

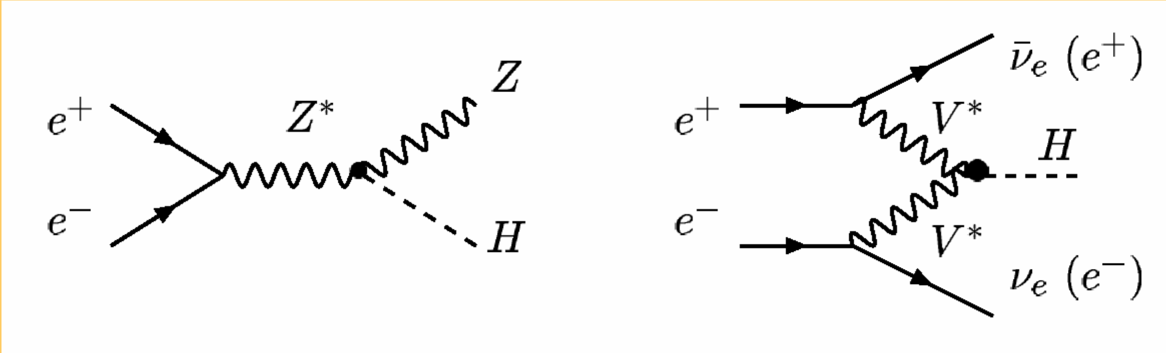
The ILC in one slide

- E = 200-500 GeV (→1 TeV?),
  - $\Delta E/E \approx O(0.1)\%$, +beamsstrahlung tail
- $L = 2\times10^{34}\ cm^{-2}s^{-1}$ (Target: 500 fb^{-1} in 4 years)
- $\sigma_{x,y,z}$ = 0.6 μm, 0.006 μm, 300 μm
- Polarization for both e^- (80%) (and possibly e^+)
  - ΔP < 0.5%
- 5 pulse trains/s, 1 train=2820 bunches in 1 ms

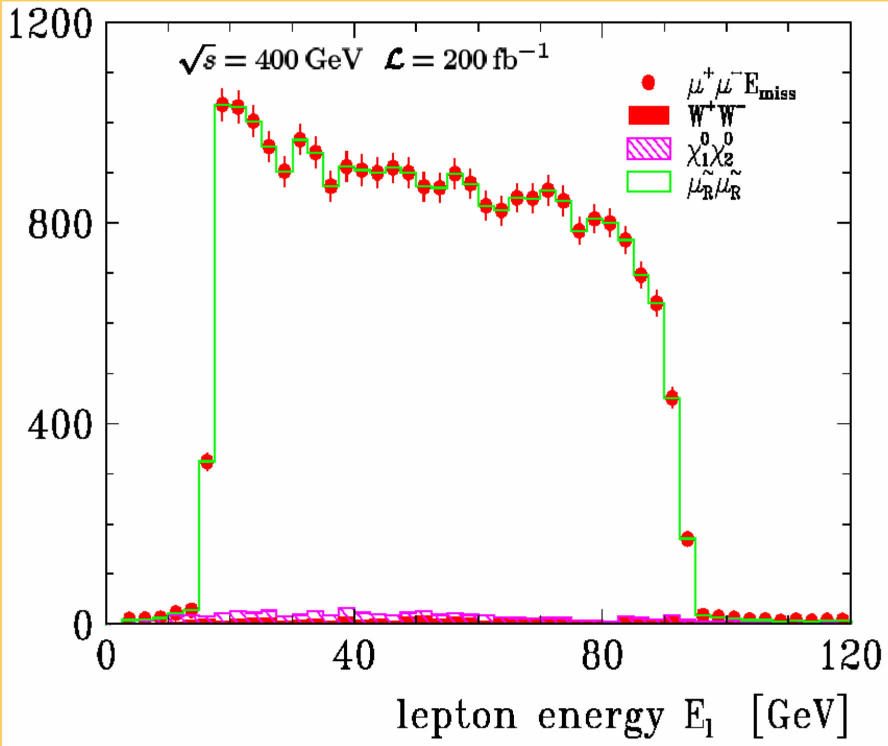


The ILC Physics Program in one slide!

- The Higgs(es)
  - Mass
  - Couplings
  - Spin



- Supersimmetry
  - Find predicted s-particles and measure masses
  - Measure couplings and quantum numbers



- Top physics
- Surprises etc.

Plan of this talk

- What challenges are posed by the physics to
  - Vertex detector
  - Tracking
  - Calorimetry

- How do we think to meet these challenges?
  - Detector concepts and ideas
  - Parameterization and optimization
  - New types of algorithms (Particle Flow Analysis)

- Will this be enough?
  - Current results, only Montecarlo for now
  - Later, results from test beams will be available

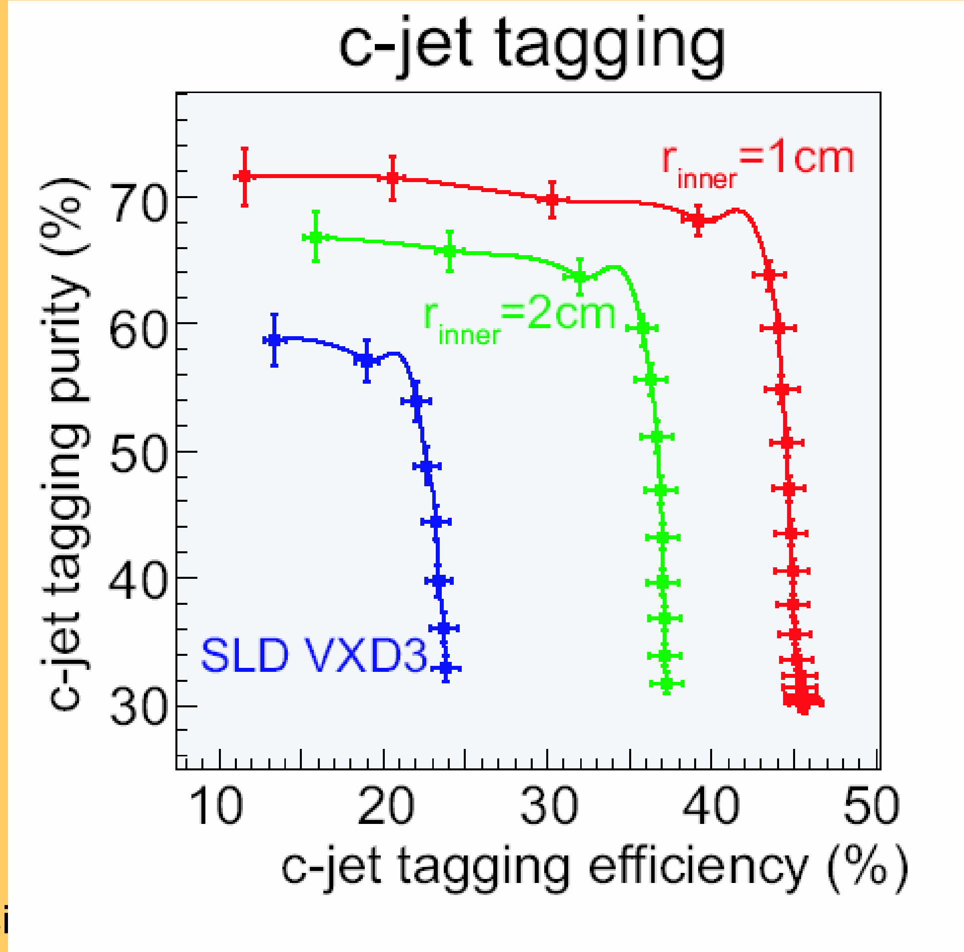
Challenge to Vertexing

- Determination of secondary and tertiary vertices with excellent resolution is key to jet flavor tagging
- To measure B.R.(H->bb^{bar},cc^{bar},gg) with fractional errors of 1%,12%,8% one needs

$$\Delta(IP_{r\varphi,Z}) \leq 5\mu m \oplus \frac{10\mu m \cdot GeV/c}{p\sin^{3/2}\theta}$$

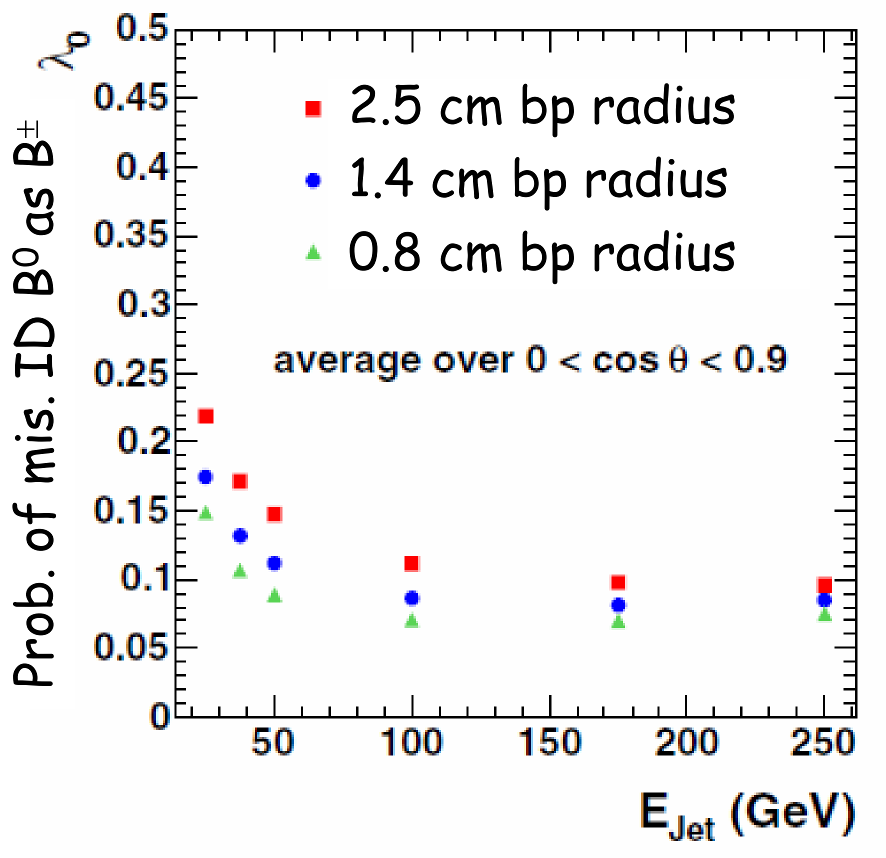
for a 120 GeV Higgs
and 500fb-1
at √s=350 GeV

- The VXD has also great importance in helping tracking!



Challenge to Vertexing

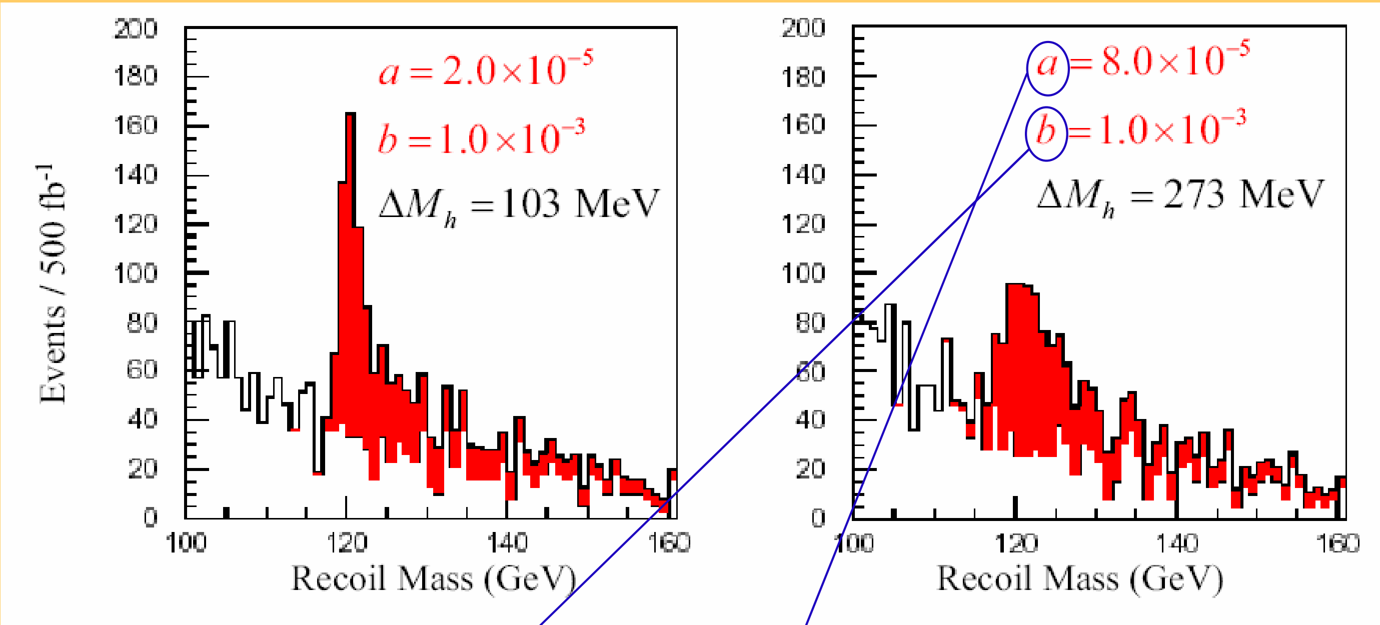
- Quark charge determination needs correct pairing of tracks –even low-Pt ones- to the right vertex
  - Needed for measurements of $A_{FB}(e^+e^- \rightarrow bb^{bar})$
- There are engineering challenges too:
  - A minimal-radius beam pipe…
  - …and exceedingly transparent…
  - …as the detector itself
  - Capacity to deal with high occupancies
  - Readout technology much faster than before…
  - …and with limited power…
  - …because of cooling needs!
- No clear solution for now!



Challenge to Tracking

- The best measurement of the Higgs mass is given by the dilepton recoil mass method in $e^+e^- \rightarrow ZH$

$$M_h^2 = s + M_Z^2 - 2E_Z\sqrt{s}$$



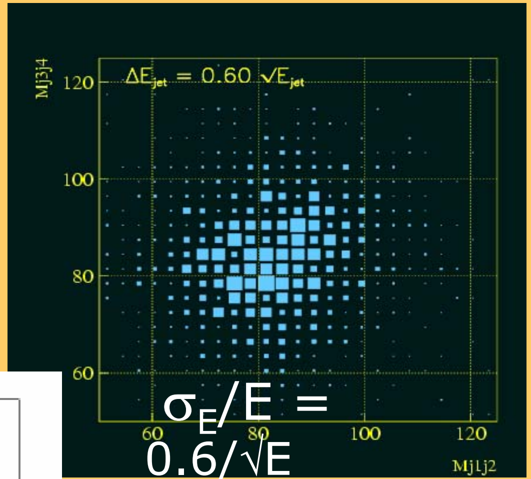
500 fb^{-1}
@350GeV

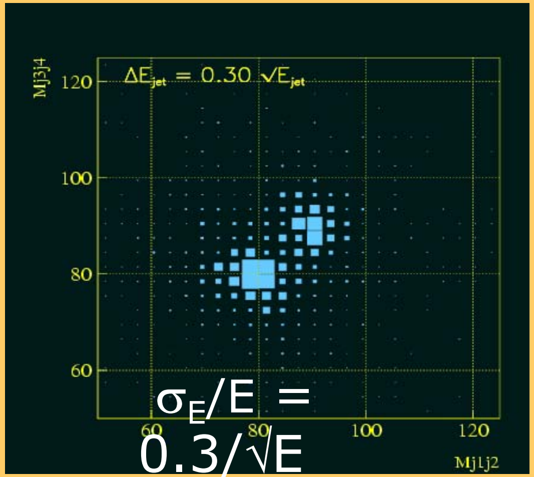
- Must stay close to the ultimate resolution on E_{Beam}

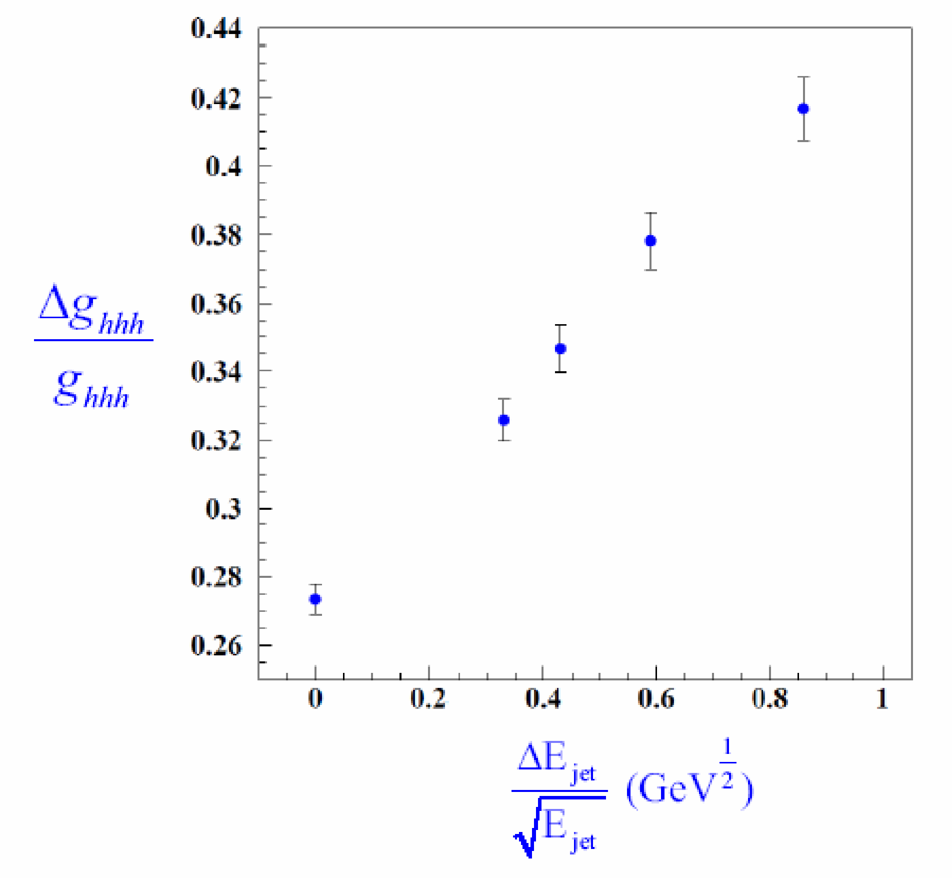
$$\Delta P_t/P_t \leq 1\text{x}10^{-3} \oplus 5\text{x}10^{-5} P_t \text{ (GeV/c)}$$

Challenge to Calorimetry

- Must be able to clearly distinguish Z from W also in their decays to hadron jet pairs



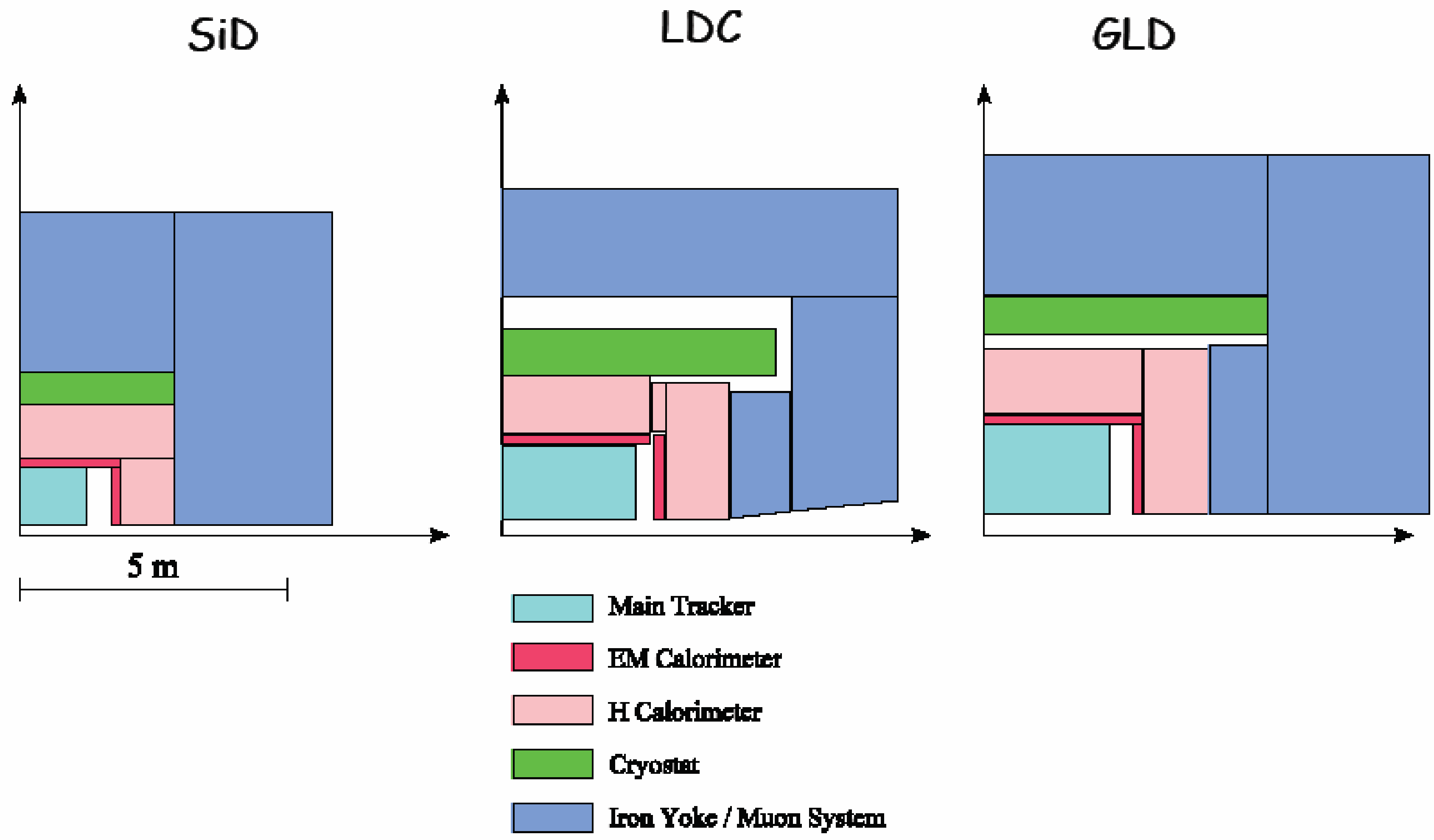




- Improvement of ΔE/E from 60%/√E to 30%/√E is
  - ✓ equivalent with ~40% luminosity gain in Δ(Higgs mass)
  - ✓ similar gain of luminosity in ΔBr(H→WW*), Δg_{hhh}, …

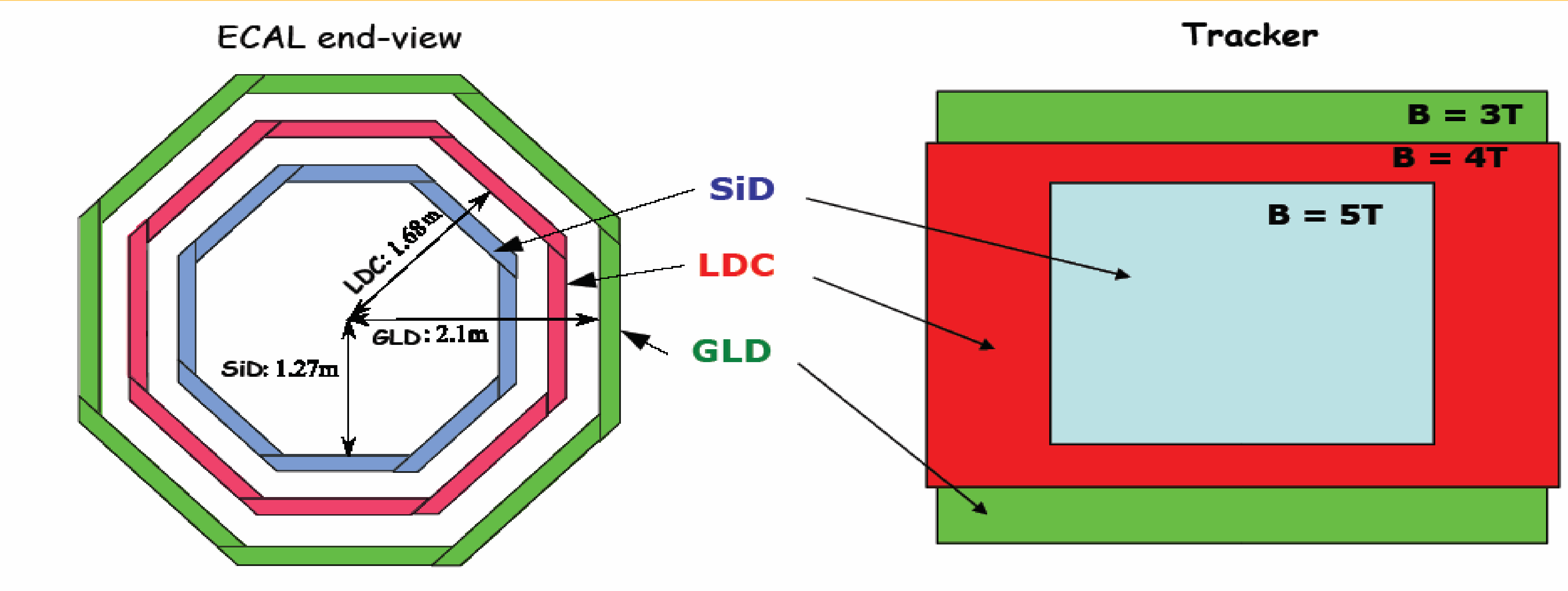
What can be done?

Detector concepts



(there is a 4th Master!)

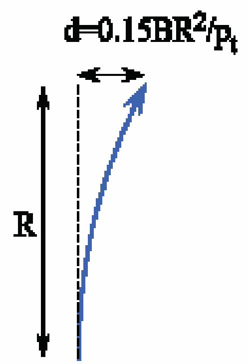
Detector concepts



A field of 4T and a measurement radius of 1.5 m implies a separation of ≈ 150 cm/P_t [GeV]

Different approaches

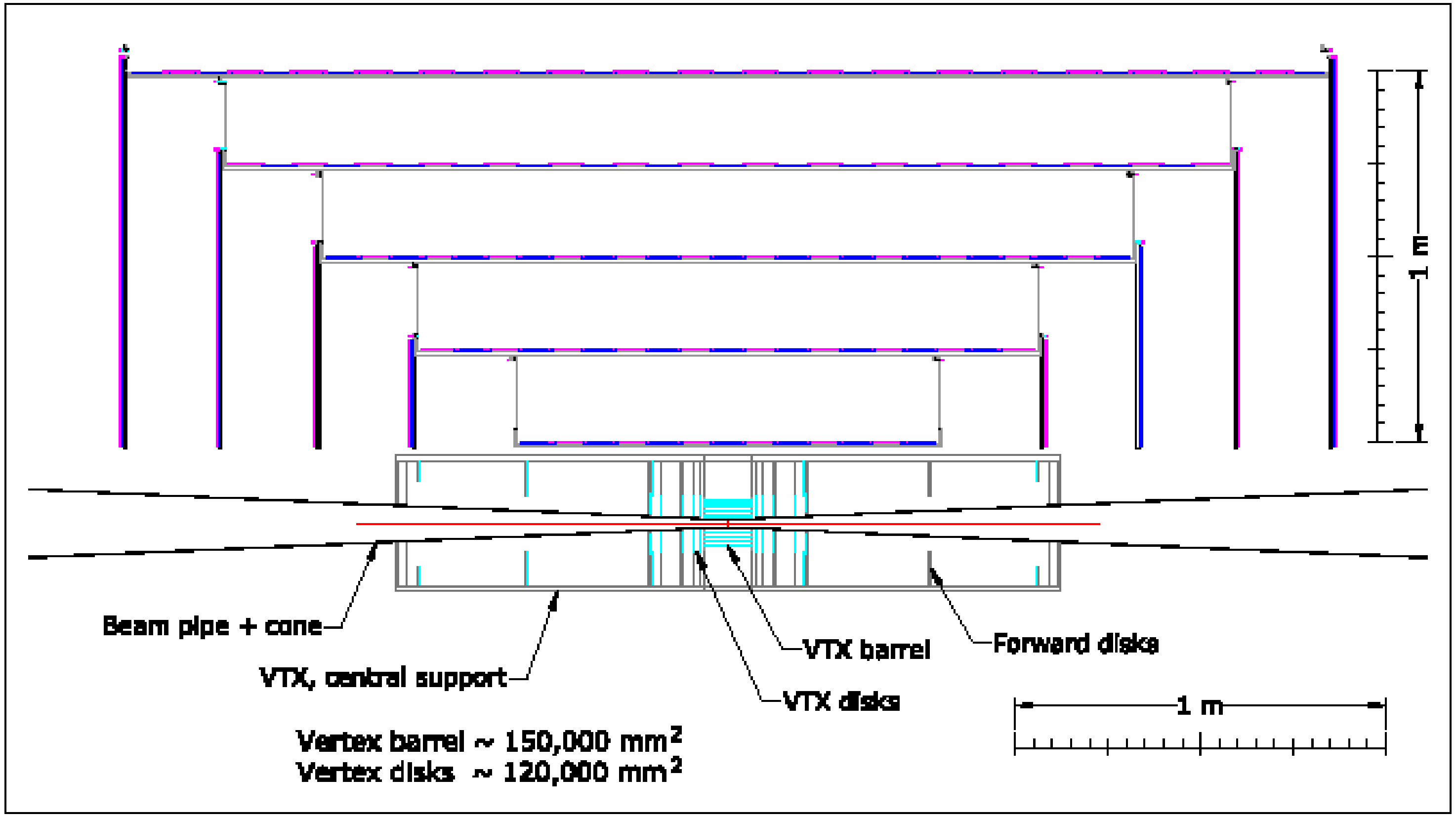
- $B R_{in}^2$: SiD
- $B R_{in}^2$: LDC
- $B R_{in}^2$: GLD



Vertex Detector

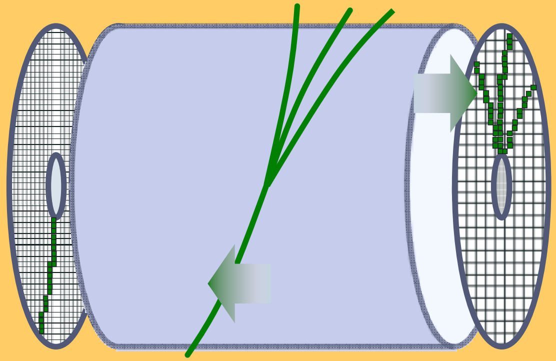
- 4~6 layers of silicon pixel detectors: long barrel or with forward disks
- Major technical challenges
  - $R_{bp} \leq$ 15mm, ~10^9 pixels of size ≤ 20μm², Layer thickness ≈0.1%X_0
  - Hardness against radiation and electromagnetic interference
  - To keep background hits occupancy low, read fast or store locally and readout later

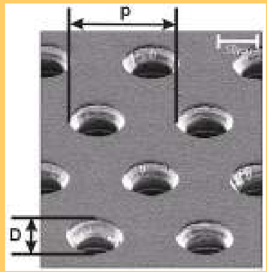
SiD concept: integrated tracker



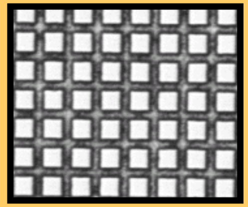
Gaseous Tracker

- Gaseous tracker : TPC
  - Robust tracking by many 3D points
  - Minimum material in tracking volume
  - Some particle ID should be possible…
  - GEM or MicroMegas will be used for gas amplification





GEM



MicroMegas

- Technical hardships
  - Minimize positive ion feedback
  - Gas selection: low diffusion, low density…
  - Operation in non-uniform B-field (Detector-Integrated Dipoles)
  - Endplate design and readout electronics
  - Demonstrate performance with a large scale prototype

Particle Flow Analysis

- PFA: measure each component of a jet in the detector best suited for it
  - Means that "components must be separated"

Component	Detector	Frac. of jet energy	Particle Resolution	Jet Energy Resolution
Charged Particles($X^{\pm}$)	Tracker	0.6	$10^{-4}\,E_X$	neg.
Photons(γ)	ECAL	0.3	$0.11\sqrt{E_\gamma}$	$0.06\sqrt{E_{jet}}$
Neutral Hadrons(h^0)	HCAL	0.1	$0.4\sqrt{E_h}$	$0.13\sqrt{E_{jet}}$

Energy resolution gives $0.14\sqrt{E_{jet}}$ (dominated by HCAL)

In addition, have contributions to jet energy resolution due to "confusion", i.e. assigning energy deposits to wrong reconstructed particles (double-counting etc.)

$$\sigma_{jet}^2 = \sigma_{x^\pm}^2 + \sigma_\gamma^2 + \sigma_{h^0}^2 + \sigma_{confusion}^2 + \sigma_{threshold}^2$$

- Single particle resolution is not the dominant contribution to jet energy resolution

Calorimeter

Particle Flow or Compensated Calorimeter

GLD, LDC, SiD

- ✓ Highly granular calorimeter
- ✓ Shower reconstruction is important
- ✓ Many longitudinal sampling
- ✓ Need excellent linkage to tracker

4th

- ✓ Compensated dual readout, Cerenkov for electrons, Scintill.light for hadrons
- ✓ Projective geometry, few longitudinal sampling
- ✓ Good resolution

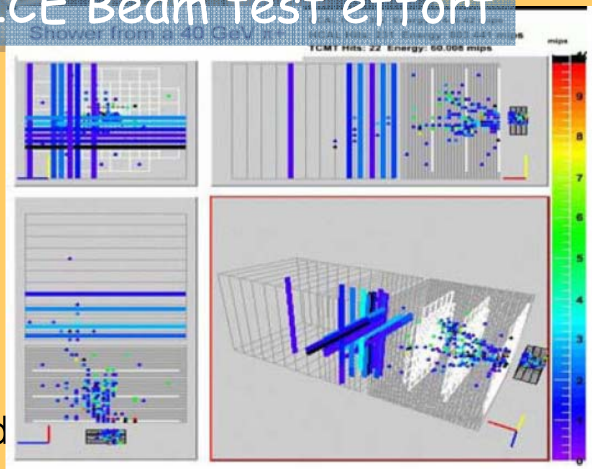
- ✓ All calorimetry, ECAL and HCAL, inside the coil
- ✓ Smallest radius possible
- ✓ Highest density → use of W to minimize thickness and Moliere radius

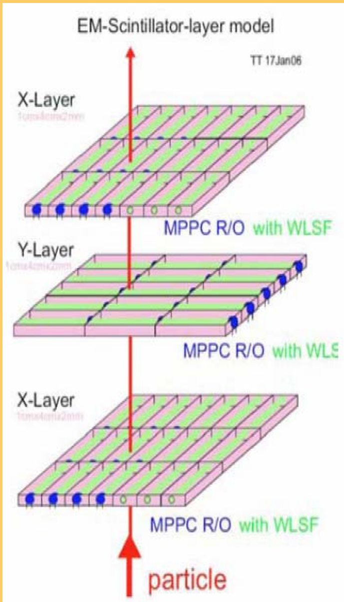
Calorimeter R&D

- Many technologies are proposed
  - ✓ ECAL – Tungsten/Lead + Silicon, Scintillator & Photon detector
  - ✓ HCAL – Lead/Iron + Scint. & Photon detector, Gas & GEM or RPC
  - ✓ Dual Readout Calorimeter (Compensating)

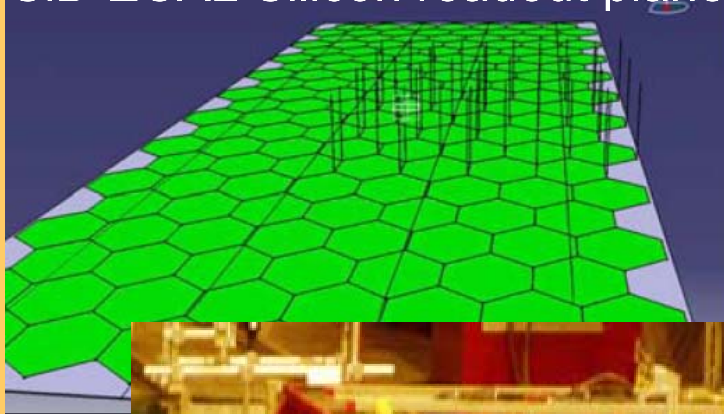
These technologies are being studied very actively.

CALICE Beam test effort





GLD ECAL
Scint.Strip



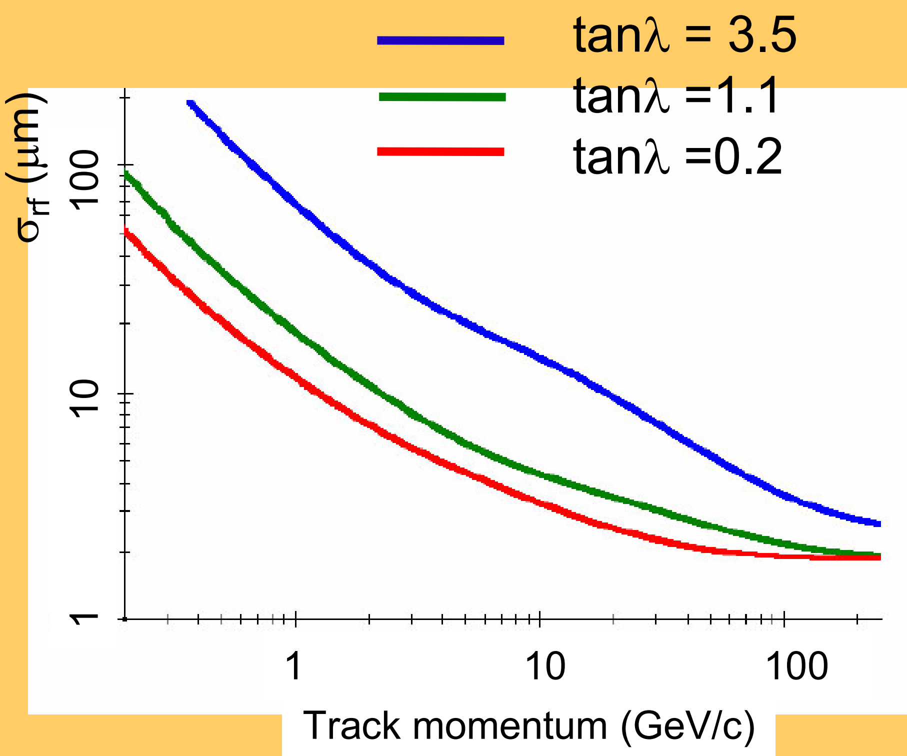
SiD ECAL Silicon readout plane

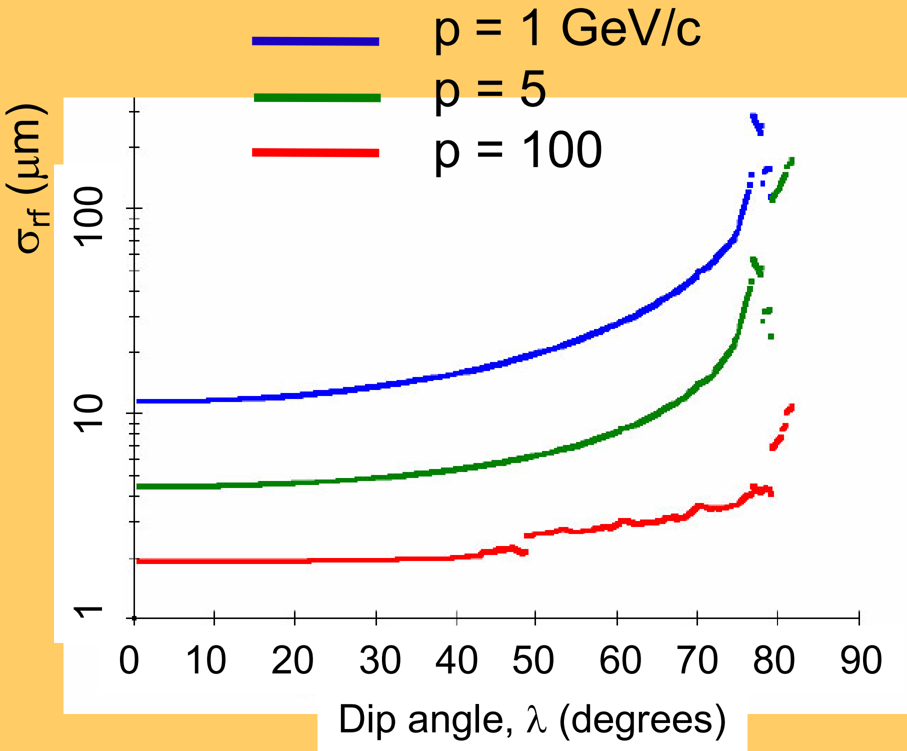
Dream beam test setup

Will this be enough?

Vertexing

- Impact parameter resolution $(\sigma_{r\varphi})$ SiD Concept

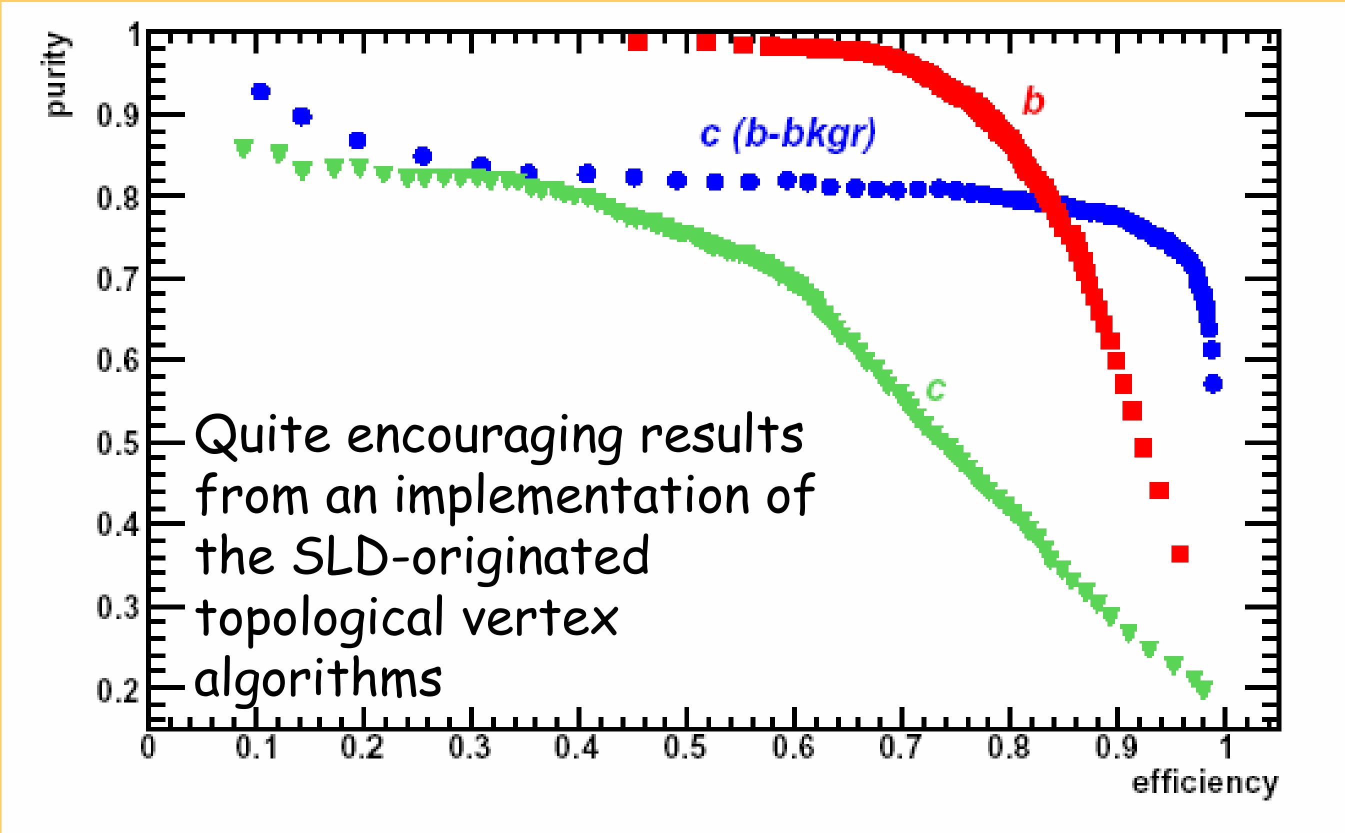




Consistent with the goal: $\Delta(IP_{r\varphi,Z}) \leq 5\mu m \oplus \frac{10\mu m \cdot GeV/c}{p \sin^{3/2}\theta}$

Vertexing: *b/c* tagging

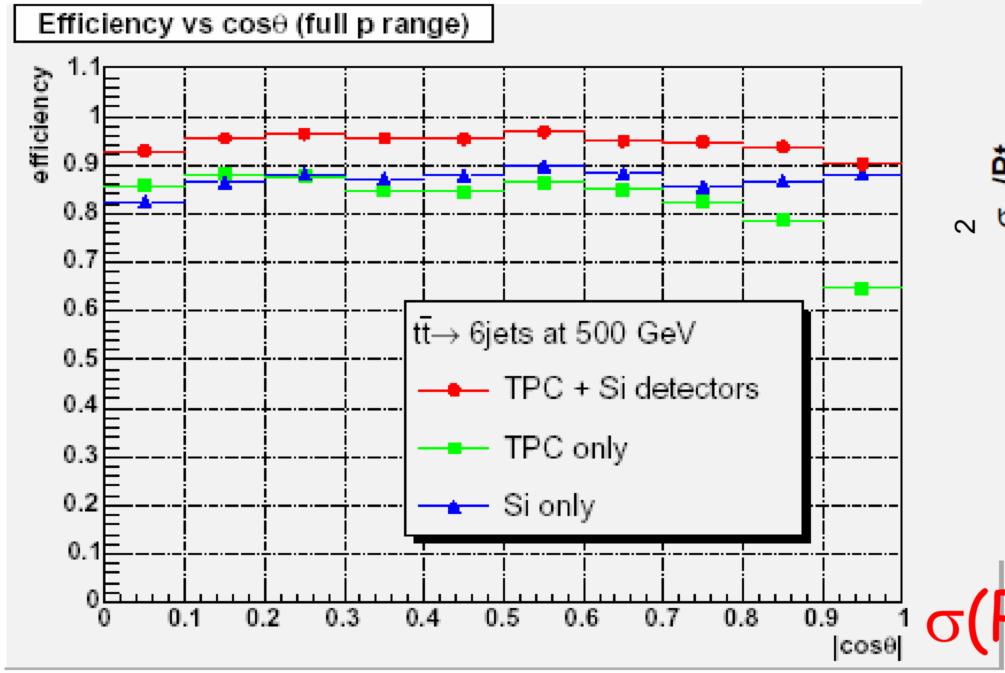
- Efficiency and purity for tagging *b*- and *c*-quark jets in Z decay studied for the LDC concept using Z->qq^{bar} events



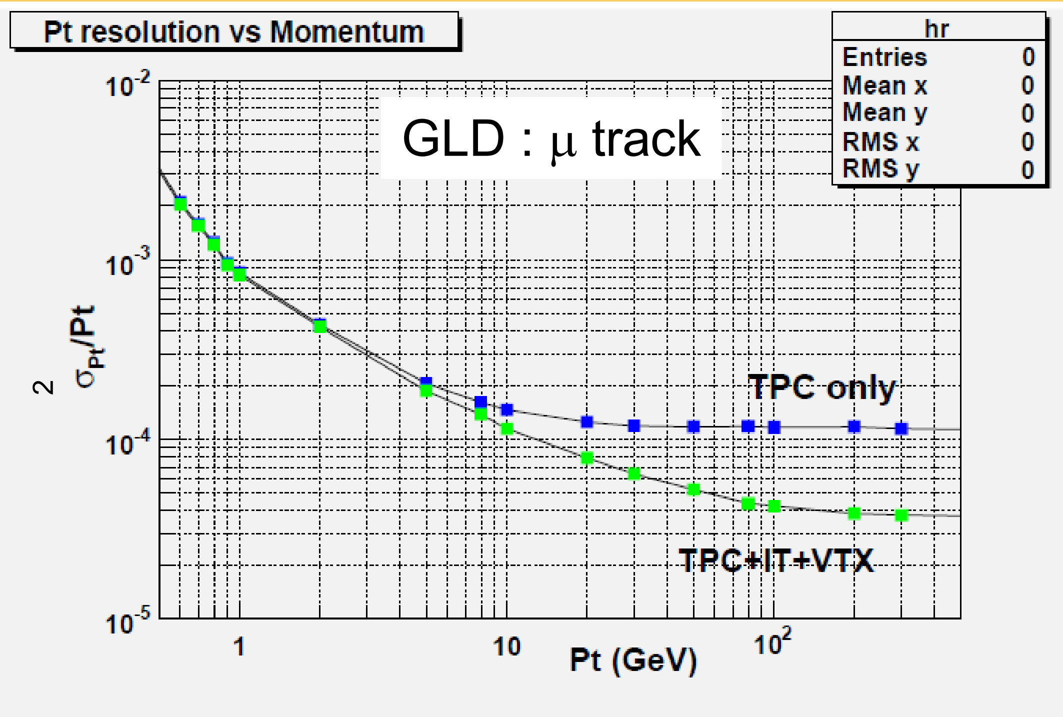
Tracking Performance

- Track finding has been studied for TPC and Silicon
  - LDC TPC: perfect B, space charge and background hits, efficiency high (94-96%) but not yet optimal
  - SiD: Inside-out track finding (VTX→ Main Si)
    η ~ 99% if a track comes from 1cm from IP ($Z \rightarrow q\bar{q}$ at $\sqrt{s}$=500GeV)

LDC : tt[bar] at 500 GeV



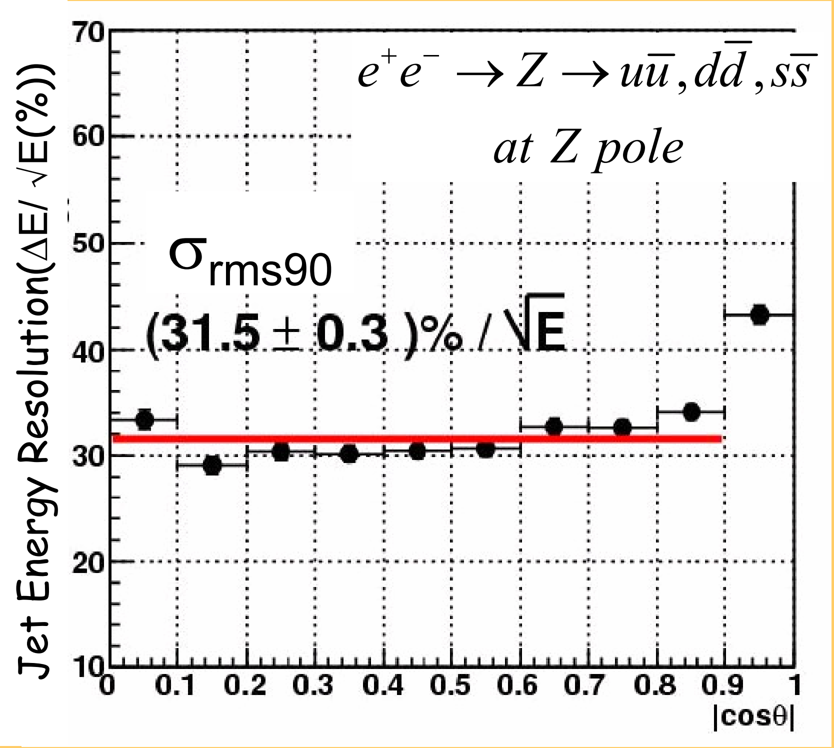
GLD : μ track



σ(Pt) and ε close to expectations!

Jet Energy Reconstruction - PFA

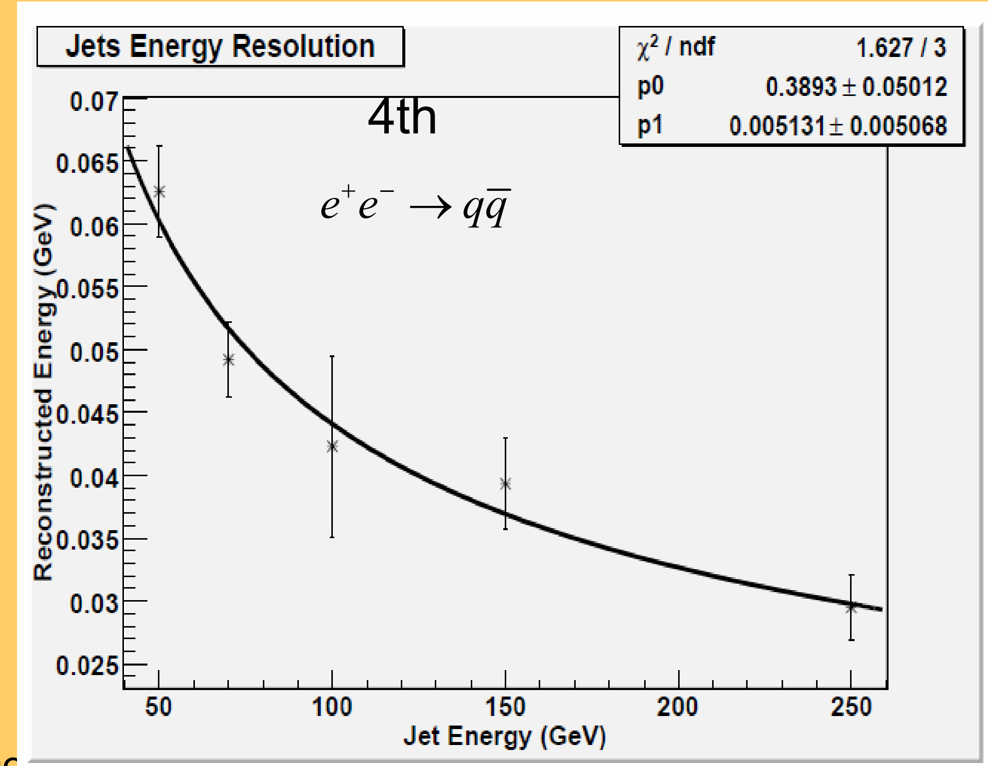
- In the barrel region of the detector, with the GLD configuration one obtains a jet energy resolution close to the target
- Further variations of the algorithm lead to improvements, but in a configuration closer to LDC



Jet Energy Resolution – Non PFA

- Dual-readout calorimeter without longitudinal segmentation
- The charged and neutral components of a jet are separated in readout elements sensitive resp. to scintillation and Cerenkov light
- "classical"-looking method, based on proximity criteria:
  - First, jet-core finding with "cone" algorithms
  - Next, clusters outside the cone get added
- Got good resolution at high energy
- Still some way to go to reach the target $\sigma_E/E=3\%$ @100 GeV

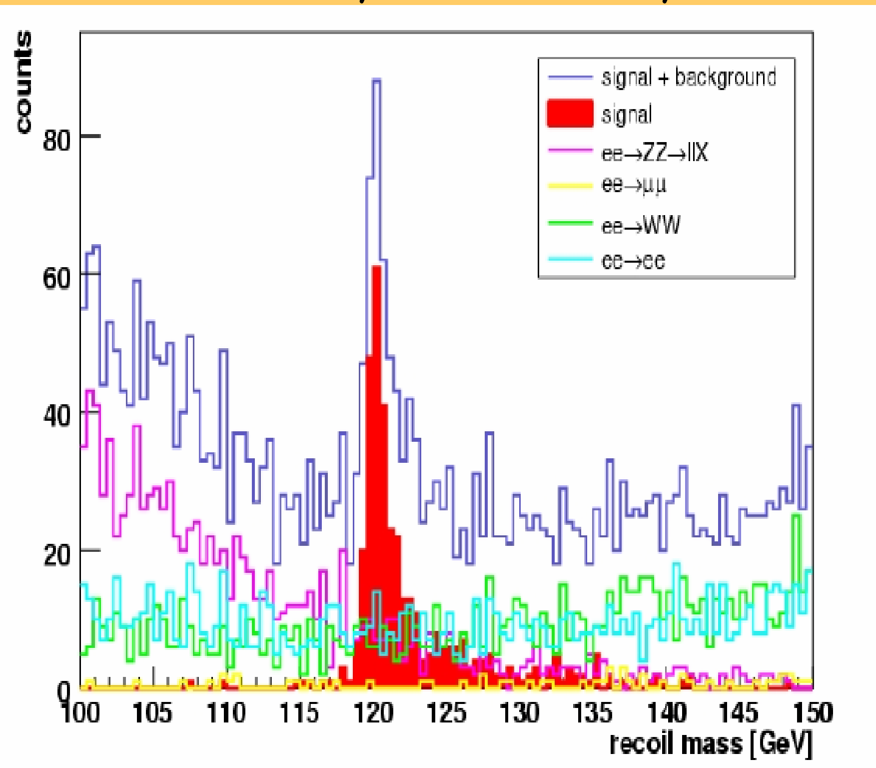
(…there is a 4th Master!)



Physics Performance: leptons

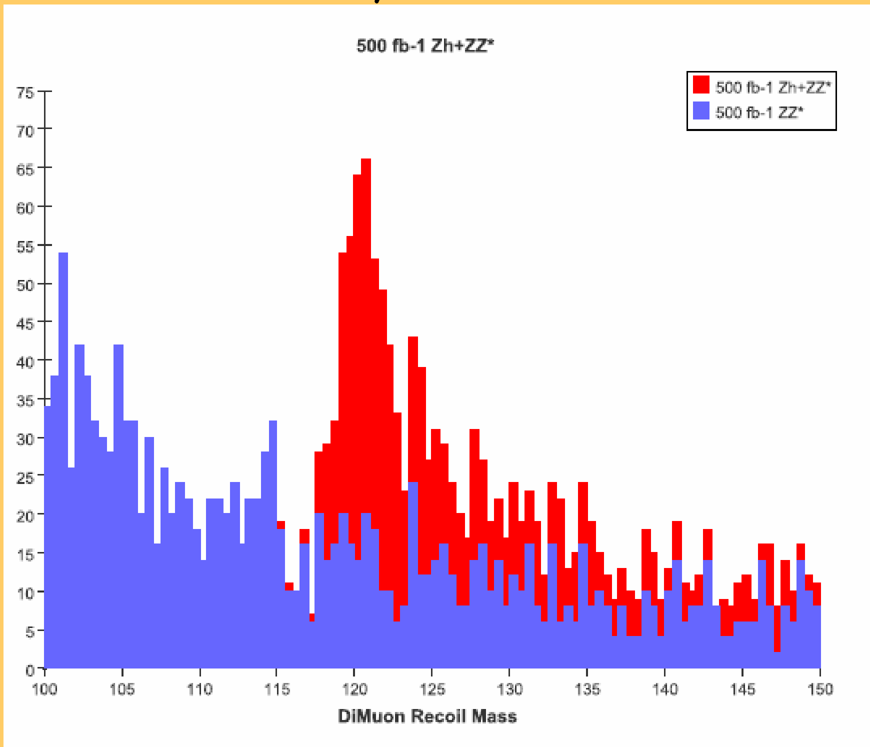
- Studies of Higgs by recoil mass measurements

✓LDC study, ILC bkg parameterized
✓Both Z→e^+e^- and Z→ $\mu^+\mu^-$
✓Near H thr., √s~250GeV, 50fb^{-1}



ΔMh~70MeV[1]

✓SiD study, ILC bkg simulated
✓Only Z→ μ+μ-
✓√s~350GeV, 500fb^{-1}

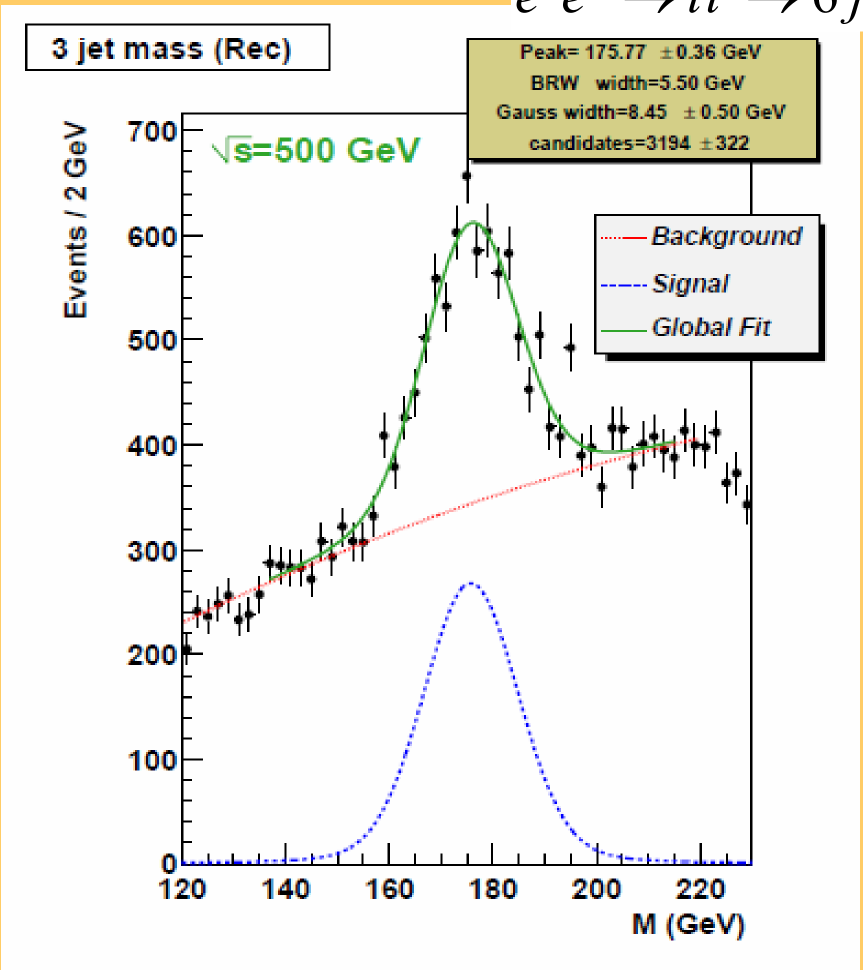


ΔMh~135MeV

First results encouraging, still much room for improvement

Physics performance: jets

$$e^+e^- \to t\bar{t} \to 6\,jets$$



- ✓300 fb^{-1} @500 GeV
- ✓Physics backgrounds via a fast simulator
- ✓Top width is about 30%/√E

A summary

- There is no doubt about the role of an ILC
  - Establish the Higgs mechanism for mass generation
  - Understand SUSY particles if seen before at LHC
  - If not, well…find them, and of course…
  - …make new discoveries!
- There is a substantial collaboration working on R&D
  - A detailed understanding of requirements is under way
  - Technological difficulties are being confronted
  - A calorimeter prototype (CALICE) already exists
  - Running options are being developed
- The future for ILC may not be very close, but it's definitely taking shape: let's believe in it!